Brest Workshop on Environmental Physics and Signal Processing: Program

I. LAGRANGIAN OCEAN DYNAMICS

Tackling the plastic soup: Using machine learning to support a clean and sustainable ocean

Erik van Sebille - Utrecht University
Monday 19 June 9h30-10h30

Large amounts of plastic waste float in the ocean. That plastic harms marine life. But where does that plastic come from? What happens to the plastic when it's in the ocean? And can we clean it up? By modelling the ocean circulation and how it transports plastic, we try to answer these questions. We use techniques from physics, mathematics, computer science and information science to better understand the physics of ocean currents. And with that understanding, we can make the world a little more sustainable.

Disentangling ocean mixing from Lagrangian trajectories and applications to algae bloom forecasting

Inga Koszalka - Stockholm University
Monday 19 June 11h00-12h00

Drifting instruments and Lagrangian simulations forced by ocean model output are often employed to quantify lateral mixing in the ocean with eddy diffusivity coefficients, turbulent kinetic energy and characteristic eddy time and length scales estimated from the trajectories. Challenges related to this approach are the high spatio-temporal variability of ocean turbulent flows and the non-local aspect of Lagrangian estimates of mixing parameters as well as the conditionality of Lagrangian statistics.

I will first address the estimation of lateral mixing coefficients using Lagrangian particle diffusivity and relative diffusivity diagnostics in the Nordic Seas, the Agulhas Current, and in the Baltic Sea, and their application to evaluation of turbulent transport in ocean models. In this respect, I will also show results from recent experiments in the Baltic Sea with drifters developed by my group at MISU. I will also shown how to "put" the biology into Lagrangian trajectories by the virtue of mathematical models for plankton dynamics, and application to the development of Lagrangian- and risk modelling tools based on the operational ocean state forecast and targeting algae bloom impacts on water quality and drinking water resources on Gotland.

II. ARTIFICIAL INTELLIGENCE AND OCEAN

Estimating lagrangian float trajectories with uncertainty with machine learning

Julien Le Sommer - CNRS

Monday 19 June 15h30-16h30

Predicting the drift of objects lost at sea is key to several operational applications such as marine pollution, oil spills, and floating wreckage. In practice, existing operational systems are based on tracking schemes, which leverage estimates of ocean surface currents and other environmental data (winds, waves) for reconstructing the drift of lagrangian particles. But, because of the chaotic nature of lagrangian dynamics, small uncertainties in the surface current, in the initial position or in the drift function can lead to large error in the predicted drift. This is why many operational systems use a combination of stochastic models and ensemble methods for accounting for uncertainty in lagrangian drift reconstructions. The lack of direct measurements of ocean surface currents in the open ocean is also problematic for practical applications, and it is not clear how to leverage ancillary data, as for instance sea surface temperature or ocean color data for lagrangian applications. In this talk, I will present results from a recently developed deep learning framework that directly models the evolution of the probability distribution of presence of objects lost at sea from various ocean surface data. I will illustrate the performance of this framework with OSSE experiments in both coastal and open ocean environments, and show how it allow to perform retrospective reconstructions of lagrangian trajectories with uncertainties from indirect and corrupted ocean data.

Joint reconstruction of ocean surface currents and temperature through deep learning algorithms

Daniele Ciani - Consiglio Nazionale delle Ricerche (CNR), Istituto di Scienze Marine
Work in collaboration with Claudia Fanelli and Bruno Buongiorno Nardelli

Tuesday 20 June 09h30-10h30

In the last decade, technological progress has opened new prospects for the application of deep-learning techniques in a wide range of fields. This change originated from the concurrent increase of computational power at widely affordable costs and impressive growth of openly available data. Computer vision is one specific branch of artificial intelligence that is driving significant improvements thanks to the possibility to design and implement complex model architectures based on deep Convolutional Neural Networks (CNN).

Within our study, the use of deep networks based on CNN is aimed at optimizing Absolute Dynamic Topography (ADT) and Sea Surface Temperature (SST) L4 observations, such as those routinely distributed within the Copernicus Marine Service. ADT and SST are strongly interconnected and both contribute to our knowledge of physical and biogeochemical processes occurring at the ocean surface/interior and at the air-sea interface. The space-based retrieval of such variables is affected by intrinsic instrumental/sampling limitations and, eventually, by degradations introduced by the optimal interpolation (OI) algorithms used to generate the Level 4 analysis maps (L4, namely gap-free field).

Here, we describe two Observing System Simulation Experiments (OSSEs) based on the outputs of an ocean general circulation model: i) in a first exercise, we derive high-resolution sea surface dynamical features by combining synthetic, low-resolution L4 ocean ADTs based on simulated satellite altimetry (resolving O(100 km) wavelengths) and higher-resolution "perfectly known" SST. This represents a different problem with respect to simple model output downscaling or single variable super-resolution, as we want to combine the information provided by channels at both original and degraded resolution in a multi-channel image, taking advantage of the physical relations among the variables as learned from the model physics and of prior knowledge of the observation geometry; ii) in a second experiment, we also introduce realistic SST L4 processing errors and modify the network to predict simultaneously high resolution SST and ADT from the simulated L4 products, in order to assess the extent to which both the SST and ADT can be improved, also introducing dynamical constraints through customized, physics informed loss functions constraining the SST small scale evolution to be driven by surface currents advection.

The neural networks are trained with OSSE data but successively tested on real satellite-based products. Our test-bed is the Mediterranean Sea, a very challenging area characterized by relatively small scale dynamics (down to 10 km)

III. CAUSALITY RELATIONSHIPS IN SIGNAL PROCESSING

Causal states and effective models from data

Nicolas Brodu - Inria
Tuesday 20 June 13h30-14h30

This work is about modeling natural phenomenon at the scale of measured data. Effective state variables are inferred, that hold information needed to predict the system. The dynamics of the object of study are then modeled in that space. The method falls within the machine learning family, but uses causal states which are based on statistical physics principles. This reduces the number of internal parameters of the model, which are mostly reduced to setting the characteristic scale of analysis for each data source and for causal relationships in time. Preliminary results will be shown in order to demonstrate the approach and show its limits. In particular, applications to modeling the ENSO phenomenon and the CO2 flux in agroecosystems.

Big whirls and small whirls talk to each other: detecting cross-scale information flow

Milan Palus - Czech Academy of Sciences
Tuesday 20 June 15h00-16h00

Big whirls have little whirls that feed on their velocity,
and little whirls have lesser whirls and so on to viscosity.

These famous words written in 1922 by Lewis Fry Richardson have become inspiration for intensively developing scientific field studying scales of climate variability and their interactions. In spite of ever growing interest in this research area, there is still need for developing efficient methodologies to diagnose the scale-to-scale energy or other physical quantities fluxes to characterize such flows quantitatively, e.g., in their strength, direction, etc. In this contribution we would like to introduce the methodology able to identify causal relations and information transfer between dynamical processes on different time scales and even quantify the effect of such causal influences. Moreover, in macroscopic systems the information transfer is tied to the transfer of mass and energy.

The detection of cross-scale causal interactions starts with a wavelet (or other scale-wise) decomposition of a multi-scale signal into quasi-oscillatory modes of a limited bandwidth, described using their instantaneous phases and amplitudes. Then their statistical associations are tested in order to search interactions across time scales. An information-theoretic formulation of the generalized, nonlinear Granger causality uncovers causal influence and information transfer from large-scale modes of climate variability, characterized by time scales from years to almost a decade, to regional temperature variability on short time scales. In particular, a climate oscillation with the period around 7-8 years has been identified as a factor influencing variability of surface air temperature (SAT) on shorter time scales. Its influence on the amplitude of the SAT annual cycle was estimated in the range 0.7-1.4^{o}C, while its strongest effect was observed in the interannual variability of the winter SAT anomaly means where it reaches 4-5^{o}C in central European station and reanalysis data. In the dynamics of El Nio-Southern Oscillation, three principal time scales - the annual cycle (AC), the quasibiennial (QB) mode(s) and the low-frequency (LF) variability - and their causal network have been identified. Recent results show how the phases of ENSO QB and LF oscillations influence amplitudes of precipitation variability in east Asia in the annual and QB scales.

IV. MULTISCALE MODELLING AND SIGNAL PROCESSING METHODS

The multifractal theory of turbulence, a framework to investigate the ocean

Jordi Isern Fontanet - Institut de Ciencies del Mar (CSIC)
Wednesday 21 June 09h30-10h30

The mulifractal theory of turbulence provides a powerful framework that connects the scaling and geometrical properties of coarse grained fields in the limit of small scales with global statistics of the flow. As it is used here, this theory is based on three main contributions: Onsagers theory of ideal turbulence; the multifractal formalism; and different models of the turbulent cascade. But, our implementation differs from common approaches in that it is based on velocity gradients rather than energy dissipation or velocity differences. If temperatures are used instead of velocities, the singularity exponents that characterize the behavior of coarse grained fields at small scales have a simple interpretation. Indeed, they can be seen as a proxy measure for the intensity of fronts, on the basis that the strongest fronts are those with the most marked singularity, hence, also those with the smallest singularity exponents. In this talk I will review the basis of the multifractal theory of turbulence and show various examples of the insight obtained in different oceanographic problems such as the study of the energy cascade from in situ velocity measurements; the analysis of ocean models; or the comparison of different satellite products of Sea Surface Temperatures.

Climate projections of extreme events: from synoptic conditions towards sub-kilometre-scale modelling

Ivica Vilibic - Ruder Boskovic Institute, Division for Marine and Environmental Research
Work in collaboration with Clea Denamiel, Danijel Belusic and Petra Zemunik
Wednesday 21 June 11h00-12h00

The overall increase in frequency and intensity of atmospherically-driven extreme events due to the ongoing climate warming is nowadays widely accepted within the scientific community. These events occur at periods from a couple of minutes to a couple of days and are highly variable in space (e.g., flash floods, tropical cyclones, storm surges, etc.). However, state-of-the-art global and regional climate models lack the appropriate resolution to reproduce most of these events while (sub-)kilometre resolutions are inadequate for long-term simulations as, to this date, they require extreme computational power and remain extremely slow (particularly for coupled atmosphere-ocean models). Therefore, till now, coastal hazard assessments have been mostly derived with proxy-based methods. Here we present a cost-effective approach for accurate hazard assessments of meteotsunami events (i.e., atmospherically-induced destructive ocean waves in the tsunami frequency band). The methodology is based on three assumptions: (1) conditions for local meteotsunami events can be seen and automatically extracted at the synoptic level, (2) uncertainty in climate projections can be captured by sub-sampling meteotsunami events only and (3) short-term atmosphere-ocean simulations are suitable for kilometre-scale reproduction of meteotsunami events. In practice, as meteotsunami events are selected with a synoptic index and downscaled from an ensemble of global models, this method allows for the accurate estimation of the climate uncertainty for any given region of interest. If proven successful for meteotsunami events, such an approach could be used to assess other climate-induced hazards (inland or along the worldwide coastlines) and, hence, to improve the adaptation plans used by the local decision makers.